FINAL SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

TOPICAL REPORT NEDE-33284P, SUPPLEMENT 1, REVISION 0

"MARATHON-ULTRA CONTROL ROD ASSEMBLY"

GE-HITACHI NUCLEAR ENERGY AMERICAS, LLC

PROJECT NO. 712

1.0 INTRODUCTION

By letter dated January 29, 2010, GE-Hitachi Nuclear Energy Americas, LLC (GEH) submitted Topical Report (TR) NEDE-33284P, Supplement 1, Revision 0, "Marathon-Ultra Control Rod Assembly," to the U.S. Nuclear Regulatory Commission (NRC) for review and approval (Reference 1). This TR provides design specifications along with mechanical lifetime and nuclear lifetime calculations for the new Marathon-Ultra control blade design. The TR was supplemented with GEH nuclear and mechanical lifetime models and calculations and GEH responses to the NRC staff's request for additional information (RAI) in letters dated March 4, 2011 (Reference 2), March 28, 2011 (Reference 3), and November 15, 2011 (Reference 4) respectively.

2.0 REGULATORY EVALUATION

Regulatory guidance for the review of fuel rod cladding materials and fuel system designs and adherence to Title 10 of the *Code of Federal Regulations* Part 50, Appendix A, General Design Criteria (GDC) for Nuclear Power Plants, GDC-10 "Reactor Design," GDC-27 "Combined Reactivity Control Systems Capability," and GDC-35 "Emergency Core Cooling" is provided in NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants" (SRP), Section 4.2, "Fuel System Design" (Reference 5). In accordance with SRP, Section 4.2, the objectives of the fuel system safety review are to provide assurance that:

- The fuel system is not damaged as a result of normal operation and anticipated operational occurrences,
- Fuel system damage is never so severe as to prevent control rod insertion when it is required,
- The number of fuel rod failures is not underestimated for postulated accidents, and
- Coolability is always maintained.

NEDE-33284P, Supplement 1, provides nuclear and mechanical design calculations for the Marathon-Ultra control blade design. The NRC staff's review of this TR is to ensure that the

Marathon-Ultra control blade design adequately addresses the regulatory requirements identified in SRP, Section 4.2.

The Marathon-Ultra control blade design has been evaluated to ensure compliance with the same licensing criteria as the original Marathon and Marathon-5S designs. As such, the NRC staff's review of the Marathon-Ultra control blade design followed the same logic as was used in the reviews for those designs (References 6 and 7).

3.0 TECHNICAL EVALUATION

The NRC staff's review of NEDE-33284P, Supplement 1, is summarized below:

- Verify that the control blade design criteria are consistent with regulatory criteria identified in SRP, Section 4.2.
- Verify that the control blade design criteria are consistent with past reviews.
- Verify that the mechanical design methodology is capable of accurately or conservatively evaluating each component with respect to its applicable design criteria.
- Verify that the nuclear design methodology is capable of accurately or conservatively evaluating boron depletion and blade worth.
- Verify that the Marathon-Ultra control blade design satisfies regulatory requirements.
- Verify that GEH's experience database supports the mechanical lifetime and nuclear lifetime being requested. If necessary, implement a surveillance program to monitor in-reactor behavior and confirm design calculations.

In addition to reviewing the material presented in Reference 1 and responses to RAIs, the NRC staff performed independent nuclear lifetime and mechanical lifetime calculations. Pacific Northwest National Laboratory (PNNL) assisted the NRC staff in the review of the Marathon-Ultra control blade component structural evaluations. PNNL's review of the Marathon-Ultra structural design analyses, documented in the attachment to this safety evaluation (SE), builds from prior reviews of the Marathon-5S and the Economic Simplified Boiling Water Reactor (ESBWR) control blade finite element analysis (FEA) models and methods.

3.1 Marathon-Ultra Mechanical Design Evaluation

3.1.1 Design Specifications

As described in Section 2 of NEDE-33284P, Supplement 1(Reference 1), the Marathon-Ultra control blade design is a derivative of the Marathon-5S design approved in Reference 6. The only differences between the two control blade designs are the absorber tube neutron poison loading pattern and the use of thin wall boron carbide (B_4C) capsules. Where Marathon-5S uses an all B_4C capsule design, the Marathon-Ultra design incorporates full-length hafnium rods in outer edge, high-depletion tube locations. The outer structure of the control rod, consisting of the handle, absorber tubes, tie rod, and velocity limiter, is identical to the Marathon-5S design.

Similarly, the component materials and manufacturing processes, including welding, are exactly the same. Table 2-1 of Reference 1 provides direct comparisons of design specifications between the two control blade designs for the different boiling water reactor (BWR) lattice configurations (e.g., C-, D-, and S-lattices).

The NRC staff understands the need for manufacturing flexibility, especially for shop maintenance and improvements. However, changes in design specifications or materials (e.g., alloying elements, thermal processing) may alter the basis for the NRC staff's approval of the Marathon-Ultra control blade design. Therefore, the NRC staff's approval is restricted to the design specifications provided within Section 2 of Reference 1, except as allowed within the provisions of Section 10 of Reference 1, as amended by the changes submitted with GEH's response to RAI-7 (Reference 4) and in accordance with Sections 3.1.1.1 and 3.1.1.2 of this SE.

3.1.1.1 Alternate Absorber Loading Patterns

A good example of design flexibility which directly impacts the NRC staff's approval was provided in Section 10 of the Marathon-5S TR (Reference 6). During its prior review for the Marathon-5S TR, the NRC staff was unwilling to accept the hafnium option since the TR lacked nuclear and mechanical lifetime calculations unique to the hafnium design. Similarly, Section 10 of Reference 1 requests approval for design flexibility which would allow alternate load patterns of B_4C capsules and hafnium rods within the Marathon-Ultra control blade design. Reference 1 states that prior to implementation of any alternate loading pattern, GEH would demonstrate that the new absorber loading patterns meets all safety, design, and operational acceptance criteria presented in the TR including, but not limited to:

- [ ]
- Demonstration of clearance between the hafnium rod and the outer absorber tube at end-of-life.
- Demonstration of acceptable stresses due to control rod scram, measured against applicable acceptance criteria.
- Demonstration of conformance to nuclear evaluation design criteria.

In response to RAI-7 regarding the alternate absorber loading patterns (Reference 4), GEH provided further details about the applicability, fixed and variable design parameters, evaluation methodologies, and acceptance criteria. In addition, a notification process consisting of a Compliance Demonstration Report is described. [

]

The material of the capsule body tubing may be varied from that shown in Table 2-1, [ ], provided the acceptance criteria described in Section 10.5 below are met.

The NRC staff had concerns with some wording in Section 10 of Reference 1, specifically the text "methodology equivalent to that in Section 4.2." The GEH response to RAI-7 clearly states that methodologies used to evaluate any future alternative absorber loading will be identical to the methodologies reviewed by the NRC staff and that the nuclear analysis methodology shall not be modified unless specifically reviewed and approved by the NRC staff.

As part of its prior review for Marathon-5S, the NRC staff performed independent calculations and audited the B10 depletion calculations and FEA mechanical calculations for the all-B_4C capsule configuration. During this review, the NRC staff performed independent calculations and audited the GEH calculations supporting the combined B_4C capsule and hafnium rod configuration. Based upon these reviews, the NRC staff finds the methodology and design criteria acceptable for developing and implementing alternate absorber loading configurations. As such, the optional absorber load patterns provision detailed in the amended version of Section 10 of Reference 1 (submitted with the RAI-7 response, Reference 4), as amended by [ ] is acceptable.

3.1.1.2 Applicability of Marathon-Ultra Design to the Advanced Boiling Water Reactor (ABWR) and ESBWR

Section 1 of NEDE-33284P, Supplement 1 (Reference 1), requests NRC approval for the use of Marathon-Ultra control rods in "Boiling Water Reactors." Section 11 of Reference 1 requests approval for design flexibility which would allow an alternate blade design applicable to the advanced reactor designs ABWR and ESBWR. The primary differences in the control rod designs are the replacement of the velocity limiter with a connector for both the ABWR and the ESBWR (coupling with a motor driven control rod drive system), and a shorter absorber section for the ESBWR.

In response to RAI-7 (Reference 4), GEH has proposed a more detailed control blade design change process by merging the alternate absorber loading and ABWR/ESBWR design options into a revised Section 10 of Reference 1. Section 11 of Reference 1 would be deleted. During its review, the NRC staff identified several methodology differences employed for the ESBWR control blade design relative to the methodology detailed in the Marathon-Ultra TR. These differences introduce uncertainty in the design change process outlined in the revised Section 10 (RAI-7, Reference 4). Furthermore, no mechanical design calculations have been provided with this TR for NRC staff review of the ABWR or ESBWR versions of the Marathon-Ultra control blade. Based upon these differences in design methodology and uncertainty in the design change process, the NRC staff's approval does not include the ABWR or ESBWR design change option for the Marathon-Ultra control blade design.

In the final, approved version of this TR, Section 10 should be modified to clearly state that the design change process is not applicable to ABWR and ESBWR. Conforming changes may also be necessary throughout the TR.

The NRC staff's SE includes a limitation defining the regulatory definition of Marathon-Ultra as the detailed description provided in Section 2 of NEDE-33284P, Supplement 1. Any deviations must be within the bounds of Section 10 of NEDE-33284P, Supplement 1, as amended to restrict applicability to BWR/2 through BWR/6.

3.1.2 Operating Experience

The original Marathon control blade design, with its unique square absorber tube geometry, has extensive operating experience in the U.S. BWR commercial fleet. As part of its approval of the original Marathon design in 1991 (Reference 7), the NRC staff imposed a surveillance program requirement for GEH to monitor and confirm the control rod performance. Attachments 2 and 3 of Reference 7 provide details of the Marathon surveillance program. The surveillance program includes the following action statement:

> "Should evidence of a problem with the material integrity arise; (1) arrangements will be made to inspect additional Marathon control rods to the extent necessary to identify the root cause and (2) if appropriate, GE shall recommend a revised lifetime limit to the NRC based on the inspections and other applicable information available."

One weakness in the Marathon surveillance plan was the lack of required periodic reporting to the NRC. This is evident from the first Marathon surveillance program status report transmitted to the NRC, which was dated February 2007. During the 15 years between its approval and introduction and the first surveillance status report, the Marathon control blade had experienced in-reactor material degradation. Specifically, cracking was observed in the control blade handles and square absorber tubes.

The latest surveillance report (Reference 8) details the results of [ ] visual examinations conducted on Marathon control blades, including the following observations:

- No crack indications have been observed on any absorber tubes containing hafnium rods.
- [

]

The Marathon-5S control blade includes features designed to address the in-reactor material degradation experienced by the older Marathon design. As part of its approval of the Marathon-5S design in 2009 (Reference 6), the NRC staff required a more rigorous surveillance program which included annual reporting requirements. Detailed visual inspections were chosen to ensure that the Marathon-5S design features were not susceptible to the same material degradation problems observed in the older Marathon control blade design. The surveillance program was designed to detect material degradation due to early-in-life failure mechanisms (e.g., stress corrosion cracking, weld degradation) and validate end-of-life mechanical design lifetime predictions (e.g., absorber tube failure). In addition, surveillance was required for control blades in each lattice type and different BWRs.

The primary difference between the Marathon-Ultra and Marathon-5S is the introduction of hafnium rods in high-duty absorber tube locations. The configuration of the Ultra hafnium rods, including the material requirements, diameter, and length, are identical to the hafnium rods used in the existing Marathon design. Based on past operating experience which has shown no indications of cracks in absorber tubes containing hafnium rods, there is reasonable assurance that the hafnium rods will behave in an acceptable manner.

Section 3.3 of this SE describes the surveillance requirements for the Marathon-Ultra control blade.

3.1.3 Mechanical Design Evaluation

The same licensing criteria used to judge the acceptability of the original Marathon (Reference 7) and Marathon-5S (Reference 6) control blade designs were used for the Marathon-Ultra design. Specifically,

1) The control rod stresses, strains, and cumulative fatigue shall be evaluated to not exceed the ultimate stress or strain of the material.
2) The control rod shall be evaluated to be capable of insertion into the core during all modes of plant operation within the limits assumed in the plant analyses.
3) The material of the control rod shall be shown to be compatible with the reactor environment.
4) The reactivity worth of the control rod shall be included in the plant core analyses.
5) Prior to the use of new design features on a production basis, lead surveillance control rods may be used.

The first three licensing criteria will be discussed in this section. Section 3.2 addresses the fourth licensing criterion, reactivity worth. Section 3.3 addresses the fifth licensing criterion, which was modified to build upon the Marathon-5S surveillance program requirements.

3.1.3.1 Stress, Strain, and Fatigue

Failure or deformation of control blade components may challenge control blade insertion or may result in a loss of reactivity worth (i.e., leaching of B_4C). GEH's licensing criterion is that stresses, strains, and cumulative fatigue shall not exceed the ultimate stress or strain of the material due to normal, abnormal, emergency, and faulted loads. The integrity of the welds under these loading conditions is also part of this criterion. This criterion is consistent with SRP, Section 4.2 and therefore acceptable.

The outer structure of the Marathon-Ultra control rod design, consisting of the handle, absorber tubes, tie rod, and velocity limiter, is identical to the Marathon-5S design. Similarly, the component materials and manufacturing processes, including welding, are exactly the same. As such, many of the Marathon-5S mechanical design analyses are directly applicable to the Marathon-Ultra design. Section 3 of NEDE-33284P, Supplement 1 details the structural evaluation for the Marathon-Ultra control blade components under various loading conditions. According to Table 3-24 of NEDE-33284P, Supplement 1, the following mechanical design analyses are unchanged from the Marathon-5S design:

- External Pressure and Channel Bow Lateral Load Analysis
- Internal Pressure Analysis
- Pressurization Stress on Absorber Tubes Analysis
- Combined Internal Pressure + Fuel Channel Bow Induced Bending Analysis

Due to slight design differences, the thermal analysis and lifting load analysis were reanalyzed for the Marathon-Ultra control rod design using the same methodology as the Marathon-5S design. PNNL's technical review of these two design analyses is documented in the attachment to this SE. In response to RAI-2 regarding the lifting load analysis (Reference 4), GEH provided an alternative lifting load evaluation including a weld quality factor. In response to RAI-7 (Reference 4), GEH confirmed that the alternate loading patterns would not exceed the maximum control blade weights listed in Table 2-1, so the alternate lifting load evaluations reported in RAI-2 cover the permissible range of the alternate absorber loads and demonstrate a positive design margin. Because the NRC staff's review relies upon the alternate lifting load evaluation provided in the RAI-2 response, rather than the methodology defined within the originally submitted Marathon-Ultra TR (Reference 1), approval of the Marathon-Ultra design and the optional design change process in Section 10 of NEDE-33284P, Supplement 1, is limited to the control blade weights listed in Table 2-1 of NEDE-33284P, Supplement 1.

The Marathon-5S control blade introduced new design features which were intended to avoid problems observed with prior control blade designs. These same features were maintained for the Marathon-Ultra control blade design and are summarized below:

- Field inspections of the existing Marathon control blades revealed cracking in the handle near the roller pin. The root cause was determined to be IASCC prompted by chemical remnants (from the manufacturing process) within the roller pin hole. Note that due to its design and geometry, it is believed that stagnant flow conditions existed in the pin hole.

This stagnant condition allows for the chemical interaction (along with mechanical loading) needed to produce IASCC. The Marathon-5S and Marathon-Ultra control blade designs eliminate the handle roller pins. Figures 2-3 and 2-4 of NEDE-33284P, Supplement 1, illustrate the spacer pad and plain extended handle design.

- Field inspections of the existing Marathon control blades revealed absorber tube cracking. These cracks may be the result of either (1) under prediction of swelling in B_4C with irradiation or (2) over prediction of strain capability in absorber tube material with irradiation. [

  ]

[ ] the limiting mechanical lifetime mechanism for the Marathon-5S and Marathon-Ultra designs is the pressurization of the absorber tubes due to the release of helium gas from the absorption of neutrons by the B_4C powder. Based upon an identical absorber tube design, the Marathon-5S internal pressurization analysis and confirmatory burst tests are applicable to the Marathon-Ultra control rod design.

The end of life ^{10}B depletion calculations demonstrate that the Marathon-Ultra design is nuclear lifetime limited for all lattice configurations. In other words, ^{10}B depletion leads to a loss of 10 percent cold worth prior to exceeding the allowable limit for internal pressure due to the associated helium release.

Based upon the applicability of previously approved Marathon-5S design analyses along with PNNL's review including its independent calculations, the NRC staff finds the Marathon-Ultra control rod mechanical design analyses acceptable.

3.1.3.2 <u>Control Rod Insertion</u>

Failure or deformation of control blade components may challenge control blade insertion. GEH's licensing criterion is that the control rod shall be evaluated to be capable of insertion into the core during all modes of plant operation within the limits assumed in the plant analyses. This criterion is consistent with SRP, Section 4.2 and therefore acceptable.

The thickness of the Marathon-Ultra wing (i.e., absorber tube cross section) is identical to the Marathon-5S and Marathon designs. Other envelope dimensions, including those for control rods with plain handles or with spacer pads, are also identical. Therefore, the fit and clearance of the Marathon-Ultra control blade in the fuel cell is identical to the Marathon-5S and Marathon which have significant operating experience.

As discussed in Section 3.1.3.1 above, mechanical design analyses demonstrate that the Marathon-Ultra design is capable of withstanding all normal, abnormal, emergency, and faulted loads without permanent deformation or failure, and therefore maintains the capability of insertion.

As discussed in Section 3.4.4 of NEDE-33284P, Supplement 1, seismic scram tests of the Marathon-5S were performed. The test facility consisted of a simulated pressure vessel and reactor internals, and a control rod drive. Prototype Marathon-5S control blades were installed and the control rod drive was set to simulate D-, C-, and S-lattice operation. GEH's criteria for the seismic testing are (1) control rod insertion within scram time requirements at Operational Basis Earthquake conditions and (2) control rod insertion at Safe Shutdown Earthquake conditions. These criteria satisfy applicable SRP requirements and are therefore acceptable.

The parameters affecting seismic scram performance are the bending stiffness of the assembly, and the overall weight of the assembly. In general, a stiffer assembly and a heavier assembly will have slower seismic scram times. The test specimens used for the Marathon-5S seismic scram tests were purposefully made heavier than production Marathon-5S assemblies as a test conservatism. The weight of production Marathon-Ultra control rod assemblies is also conservatively bounded by the weight of the test assemblies. Because the outer structure of the Marathon-Ultra is identical to the Marathon-5S, the lateral bending stiffness will also be identical. Therefore, the Marathon-5S seismic scram tests apply equally to the Marathon-Ultra control blade design.

Based upon the applicability of previously approved Marathon-5S design analyses and seismic testing, the NRC staff finds that the Marathon-Ultra control blade design satisfies the control rod insertion licensing criterion.

3.1.3.3 Control Rod Material

GEH's licensing criterion is that the material of the control rod shall be shown to be compatible with the reactor environment. This criterion is consistent with SRP, Section 4.2 and therefore acceptable.

The Marathon-Ultra control blade design uses the same materials as the Marathon and Marathon-5S control rod designs. No new material has been introduced. The Marathon-Ultra and Marathon-5S share the same absorber tube design made from the same high-purity stabilized type 304 stainless steel as the Marathon absorber tubes. Material testing and the service history of the Marathon control rod blades confirm the compatibility of the materials with the reactor environment.

One of the top challenges facing operating BWRs is shadow corrosion induced channel bow and resulting control blade interference. Deep control blade insertion programs are sometimes used to hold down excess reactivity in order to achieve longer operating cycles. The close proximity of the type 304 stainless steel blades with the zircaloy channel boxes for extended duration could result in shadow corrosion. The industry has developed fuel management programs coupled with augmented surveillance programs to aid in managing channel bow. Changes in channel design and materials are also being introduced to limit control blade interference. At this time there does not appear to be an easy fix to this phenomenon besides channel replacement; however, there is no evidence that any features of the Marathon-Ultra design will exacerbate the problem.

Based upon in-reactor service of these materials, the NRC staff finds that the Marathon-Ultra design has satisfied this licensing criterion.

3.2 Marathon-Ultra Nuclear Design Evaluation

3.2.1 Design Specifications

Section 4 of Reference 1 details the Marathon-Ultra nuclear evaluation design criteria and depletion methodology. Section 4.1 states that "a control rod's nuclear worth characteristics shall be compatible with reactor operation requirements." Using precedence from the approved Marathon-5S control blade design (Reference 6), GEH meets these compatibility limits by demonstrating that the initial hot and cold control blade reactivity worths are within ±5 percent $\Delta k/k$ (defined by $1-k_{con}/k_{unc}$) of the original equipment design worth.

GEH defines the control blade nuclear lifetime as "the quarter-segment depletion at which the control rod cold worth ($\Delta k/k$) is 10 percent less than its zero-depletion cold worth." (Reference 1, Section 4.1). As discussed previously, a new design may have an initial cold worth that differs by up to ±5 percent of the initial cold worth of the original equipment control blade. The end of nuclear lifetime for the new control blade design is defined as the quarter-segment depletion at which the cold worth is the same as the end of nuclear lifetime cold worth of the original equipment control blade that it is replacing. The NRC staff agrees with this approach with the understanding that a new design is always compared with the original equipment nuclear design (e.g., Duralife) and not the control blade design that is being replaced if multiple control blade design replacements have occurred over the plant's lifetime.

3.2.2 Nuclear Design Evaluation

The goal of this review was to verify that the end of nuclear lifetime for the control blade is being calculated appropriately. Proper determination of the end of nuclear lifetime is important to ensure that a given control blade always satisfies the established reactivity worth criteria for safe operation of the blade with respect to reactivity control. This was done by verifying the underlying modeling assumptions, reviewing the calculational models, and performing independent confirmatory analyses.

3.2.2.1 Methodology

The nuclear lifetime for a particular control blade is calculated by the use of a two-dimensional Monte Carlo analysis applied in a step-wise fashion in order to account for ^{10}B depletion over time. For each time step, the poison reaction rates are assumed to be constant and the poison inventories are calculated in each discrete area of the blade. The poison number densities are then updated by averaging on a cell by cell basis and the process is repeated until the reduction in cold worth reaches the end of nuclear lifetime criterion. This process was used and approved previously for the Marathon-5S control blade design (Reference 6).

The main code used by GEH to calculate the amount of ^{10}B depletion and the various k-effective values used to determine the change in cold worth is MCNP4A. Use of this code was approved in the NRC staff's SE of the Marathon-5S TR (Reference 6). Important parameters in the MCNP4A input were verified such as model geometry, moderator densities (including verification of the stated void fraction), and nuclear data (including the proper temperature specification and physics models). The geometry was also checked for errors using a visualization program.

3.2.2.2 Nuclear Lifetime and Initial Control Blade Worth

The NRC staff reviewed the Marathon-Ultra control blade nuclear lifetime and initial blade worth results for the D-, C-, and S-lattice designs as calculated by the methodology described in Section 3.2.2.1 of this SE. The control blade designs and corresponding fuel bundle designs that they will control, are described in Section 4 of Reference 1. A sample of these designs, the S-lattice, was chosen for more in-depth review. The S-lattice design contains [

] As was previously stated, the end-of-life criterion for the original equipment control blade is a 10 percent change in cold worth occurring in any quarter segment of the control blade. The end of nuclear lifetime for the new control blade design is reached when the cold worth is the same as the end of nuclear lifetime cold worth of the original equipment control blade. The amount of ^{10}B depletion calculated at this point (expressed as a percent of the initial loading) then becomes the quarter segment control blade depletion limit which defines the control blade end of nuclear lifetime.

The confirmatory analysis for the S-lattice design relied on the T-DEPL calculational sequence of the TRITON module within the SCALE 6 software suite (Reference 9). The model was built according to the S-lattice specifications given in Table 4-15 and fuel lattice information given in Figure 4-3 of Reference 1. The confirmatory model was also visually compared with the MCNP4A model for consistency. Figure 3.2-1 of this SE shows the two models side-by-side.

As documented in RAI-3 of Reference 4, the NRC staff calculated a different change in relative worth versus equivalent ^{10}B depletion curve compared to GEH's curve given in Figure 4-6 of Reference 1. The NRC staff noticed that GEH's curve showed a similar trend but appeared to be shifted by some amount. GEH indicated in its response that the curve was adjusted to match the reactivity worth of the zero-depletion original equipment in order to satisfy the mandatory matched-worth criterion. After accounting for the initial reactivity worth value for the original equipment blade (given in Table 4.8 of Reference 1) in the confirmatory analysis, the NRC staff reached the same end of nuclear lifetime result as GEH. The NRC staff consequently determined that the methodology described in Sections 4.1 and 4.2 of Reference 1 was correctly implemented.

GEH performed the control blade depletion calculations assuming fresh fuel throughout the period of irradiation. The NRC staff questioned the conservatism of the assumption in RAI-4 (Reference 4). GEH responded by stating that assuming fresh fuel throughout control blade depletion is conservative since the beginning of life fuel state gives the highest fission density. Consequently, the maximum neutron flux is being imposed on the surrounding blade throughout the entire depletion calculation. The NRC staff confirmed this by performing two separate depletion calculations. One calculation was analogous to GEH's assuming fresh fuel throughout irradiation and the other depleted the fuel materials in addition to the control blade absorber materials. For the fresh fuel calculation, the maximum flux (averaged over all fuel pins containing 4.9 percent enriched UO_2) was [

] The NRC staff also looked at the neutron flux in the B_4C to observe the impact of the fresh fuel assumption throughout control blade depletion, and as stated by GEH and confirmed in the NRC staff's analysis (see Figure 3.2-3), this assumption does maximize the flux seen in the B_4C. Since the NRC staff observed that GEH's method is conservative, the NRC staff agrees with the presented approach.

The NRC staff also questioned the assumed 40 percent void fraction in the MCNP4A analysis. GEH uses a limiting axial profile shape corresponding to end-of-life to determine which quarter segment of the control blade is most limiting. Based on the shape provided and the results of GEH's analysis, the limiting segment occurs toward the bottom of the control blade relative to its positioning in the core. This indicates that a lower void fraction might actually be seen at this limiting quarter segment. Consequently, the NRC staff issued RAI-5 asking GEH to explain the basis for the 40 percent void fraction and whether or not this assumption is conservative (Reference 4). GEH explained that while the absorber depletion rate may be sensitive to the assumed void fraction, the depletion limit is not. The NRC staff performed a sensitivity study at a void fraction of 20 percent to verify this and the results show that using a lower void fraction gives the same result as the 40 percent void fraction case. Figure 3.2-4 shows the results of the NRC staff's sensitivity study. Since GEH's statement that the assumed void fraction is independent of the control blade depletion limit was confirmed, the NRC staff found the approach to be acceptable.

In RAI-6, the NRC staff questioned the treatment of the hafnium absorber during the depletion calculation since the end of nuclear lifetime is related only to ^{10}B depletion (Reference 4). The NRC staff also asked whether alternate absorber loading patterns would invalidate the claim that the Marathon-Ultra control blade design is nuclear lifetime limited. Based on the response provided by GEH, the hafnium absorptions are converted to equivalent ^{10}B absorptions and are included in the determination of the total amount of ^{10}B depletion as a function of the change in control blade cold worth. This is done by preserving the reaction rates which are calculated in MCNP4A. The NRC staff finds this treatment acceptable since it only serves to simplify the tracking of the absorber material under irradiation and does not affect the control blade depletion limit. GEH also referred to Section 10 of Reference 1 stating that the impact of alternate absorber loading patterns on nuclear and mechanical lifetime shall be evaluated on an as-needed basis further stating that a technical SE must demonstrate that all safety, design, and operational acceptance criteria will be met before any loading patterns are offered. The NRC staff finds that re-analysis of all future proposed loading patterns using the same stipulations used for the currently proposed pattern is acceptable to indicate whether the future pattern will be nuclear or mechanical lifetime limited.

3.2.2.3 Radial Peaking Profile

One important aspect of the end of mechanical lifetime calculation is determining the radial peaking profile across the absorber wing. The mechanical tube limit is based on the amount of helium pressurization as a result of nuclear interactions within the control blade tubes containing ^{10}B. The radial peaking profile factors into the control blade mechanical design since tubes with high radial peaking have a proportionally higher pressure due to an increased reaction rate which influences the allowable number of absorber capsules in a given absorber tube. This is important in determining the feasibility of a given absorber loading pattern for a given control blade design.

Furthermore, the radial peaking profile needs to be calculated correctly so that it can be accurately determined that the design is either nuclear lifetime or mechanical lifetime limited. The ^{10}B depletion is compared to the mechanical lifetime limit by using the axial and radial profiles to determine the amount of localized depletion occurring in each of the 24 nodes in GEH's model. Once the profiles have been applied to each node in a given absorber tube, the average ^{10}B depletion is calculated and compared to the tube mechanical limit which is determined as part of the mechanical analysis. [

]

Radial peaking for a given absorber tube is calculated by tallying the total reaction rate in the tube and normalizing by the average reaction rate among all tubes. The peaking factor calculated by GEH for the [ ] and is consistent with the NRC staff confirmatory case that calculated a value of [ ]. The radial peaking profile calculated by the NRC staff was also seen to be consistent with that calculated by GEH. Figure 3.2-5 shows both GEH and NRC staff calculated profiles. Based on the NRC staff's review and the result of the confirmatory calculation, there is reasonable assurance that the radial peaking profile is being correctly calculated and applied so that the absorber tubes are designed to be within the established mechanical limits.

[

]

[

]

Figure 3.2-1: 2-D View of Modeled S-Lattice Fuel Bundle.
(Triton Model on Top, MCNP4A Model on Bottom)

[

]

Figure 3.2-2: Averaged Neutron Flux for the 4.9 Percent Enriched UO2 Fuel Pins

[

]

Figure 3.2-3: Neutron Flux in the Innermost B-10 Ring of the Innermost B-10 Cell

[

]

Figure 3.2-4: S-Lattice CRB Cold Worth Reduction

[

]

Figure 3.2-5: Radial Peaking Factors for the S-Lattice CRB Calculated with KENO-VI.

3.3 Marathon-Ultra Surveillance Program

Due to limited in-reactor service and no post-irradiation examinations for the Marathon-5S/Marathon-Ultra control blade designs, a surveillance program is necessary to confirm acceptable performance and lifetime calculations. The Marathon-5S surveillance program (Reference 6) was designed to detect material degradation due to early-in-life failure mechanisms (e.g., stress corrosion cracking, welding degradation) and validate end-of-life mechanical design lifetime predictions (e.g., absorber tube failure). In addition, surveillance is required for control blades in each lattice type and different BWR plants.

Section 6.5 of NEDE-33284P, Supplement 1 defines the proposed surveillance program for the Marathon-Ultra control blade design. This program is designed to complement the existing Marathon-5S surveillance program. In response to RAI-8 regarding the surveillance program (Reference 4), GEH provided further detail and proposed an additional inspection requirement. The amended surveillance program is listed below.

- A minimum of two (2) Marathon-Ultra control rods will be inserted in high duty locations in a D, C, or S lattice, domestic or international BWR.
- Additional Marathon-Ultra control rods may be inserted in other domestic BWRs, with the intent that they remain at a lower depletion than the two lead-depletion Marathon-Ultra control rods at the designated BWR. Should other control rods at a domestic or international BWR become the highest depletion in the BWR fleet, they will become the control rods inspected per this surveillance program.
- The two lead-depletion control rods will be irradiated, achieving as close to nuclear end-of-life as practical (target minimum 90% of end-of-life).
- For refueling outages in which the depletion of the lead Marathon-Ultra assemblies are greater than 75% of design nuclear life, the two (2) highest depletion Marathon-Ultra control rods will be moved to the spent fuel pool, with a visual inspection of all eight faces of each control rod performed. Lead Marathon-Ultra control rods may exceed 75% depletion prior to the eight-face inspections planned in the spent fuel pool as long as those inspections are performed before the control rods are utilized in another fuel cycle.
- For Marathon-Ultra control rods inserted in the opposite lattice type as the lead depletion units, two (2) highest depletion control rods shall be visually inspected during refueling outages in which the depletion of the control rods exceeds 90% of design nuclear life. These visual inspections shall consist of an inspection of all eight faces of the control rod. For the purpose of this surveillance program, D and S lattice applications are considered equivalent, since the geometry of the absorber tubes and capsules are identical. For example, if the lead depletion control rods are in a D or S lattice plant, inspections of the lead C lattice Marathon-Ultra control rods shall be performed during outages for which the depletion exceeds 90% of the design nuclear life. Conversely, if the lead depletion Marathon-Ultra control rods are in a C lattice plant, additional inspections of D or S lattice Marathon-Ultra control rods shall be performed during outages for which the depletion exceeds 90% of the design nuclear life.

- To confirm the end-of-life performance of the Marathon-Ultra control rod, the first twelve (12) control rods of each lattice type (D/S lattice and C lattice) shall be visually inspected upon discharge, for a total of 24 visual inspections, not to exceed four (4) control rods from any single plant. These visual inspections shall consist of an inspection of all eight faces of each control rod.
- Should a material integrity issue be observed, GEH will (1) arrange for additional inspections to determine a root cause and (2) if appropriate, recommend a revised lifetime limit to the NRC based on the inspections and other applicable information available.
- If, after the completion of the end-of-life visual inspection of the first twelve (12) control rods of each lattice type are complete, additional control rods reach a ¼ segment depletion that is 5% higher than the twelve inspected control rods, a minimum of four (4) of the additional control rods shall be visually inspected.
- GEH will report to the NRC the results of all Marathon-Ultra visual inspections at least annually.

The NRC staff finds that the proposed surveillance program provides reasonable assurance that material degradation mechanisms will be identified, evaluated, and reported in a timely fashion and therefore is acceptable.

4.0 LIMITATIONS AND CONDITIONS

Licensees referencing NEDE-33284P, Supplement 1 must ensure compliance with the following conditions and limitations:

1) In the approved (-A) version of NEDE-33284P, Supplement 1, Section 10 shall be revised according to the changes submitted with GEH's response to RAI-7 and the requirements of Sections 3.1.1.1 and 3.1.1.2 of this SE.
2) Except as allowed within the provisions of Section 10 of NEDE-33284P, Supplement 1, as amended by the changes submitted with GEH's response to RAI-7 and in accordance with Sections 3.1.1.1 and 3.1.1.2 of this SE, the Marathon-Ultra control blade design is restricted to the design specifications provided within Section 2 of NEDE-33284P, Supplement 1. Changes in component design, materials, or processing specifications may alter the in-reactor behavior of this design and the basis of the NRC staff's approval. Specifically:
    a) Approval of the Marathon-Ultra control rod design is limited to application in the BWR/2 through BWR/6 lattice configurations defined in Table 2-1 of NEDE-33284P, Supplement 1. The optional ABWR and ESBWR Marathon-Ultra control rod design is not part of this approval.
    b) Approval of the Marathon-Ultra control rod design is limited to the ranges in control rod weight listed in Table 2-1 of NEDE-33284P, Supplement 1.
    c) Approval of the Marathon-Ultra control rod design is limited to natural ^{10}B. Enriched B_4C powder (i.e., artificial increase in ^{10}B isotopic concentration) was not considered in the

NRC staff's review and therefore is not permitted.

d) Approval of the Marathon-Ultra control blade design is limited to 304L capsules.

3) The inspection and reporting requirements in the Marathon-Ultra surveillance program, detailed in Section 3.3 of this SE, must be fulfilled.

5.0 CONCLUSION

Based upon its review of NEDE-33284P, Supplement 1, and the required surveillance program, the NRC staff finds the Marathon-Ultra control blade design acceptable for licensing applications in BWR/2 through BWR/6 power plants. Licensees referencing this topical report must comply with the limitations and conditions listed in Section 4.0.

Section 7 of NEDE-33284P, Supplement 1 details the impact of the Marathon-Ultra control blade design on standard plant technical specifications and concludes that there is no effect from the introduction of the Marathon-Ultra design. Since the details of each plant's technical specifications may vary, it is up to each licensee to determine if the introduction of the Marathon-Ultra control rod design necessitates a license amendment.

6.0 REFERENCES

1. Letter from GEH to NRC, MFN 10-034, "NEDE-33284P Supplement 1 and NEDO-33284 Supplement 1, 'Licensing Topical Report (LTR) Marathon-Ultra Control Rod Assembly,'" dated January 29, 2010. (ADAMS Package Accession No. ML100331610)

2. Letter from GEH to NRC, MFN 11-043, "Information Request Regarding the NRC Staff Review of NEDE-33284P, Supplement 1, 'Marathon-Ultra Control Rod Assembly' (TAC No. ME3524)," dated March 4, 2011. (ADAMS Accession No. ML110760290)

3. Letter from GEH to NRC, MFN 11-133, "Finite Element Analysis Information Request Regarding the NRC Staff Review of NEDE-33284P, Supplement 1, 'Marathon-Ultra Control Rod Assembly' (TAC No. ME3524)," dated March 28, 2011. (ADAMS Accession No. ML11104A0230)

4. Letter from GEH to NRC, MFN 11-245, "Response to Request for Additional Information Re: GE-Hitachi Nuclear Energy Americas Topical Report NEDE-33284P, Supplement 1, 'Marathon-Ultra Control Rod Assembly' (TAC No. ME3524)," dated November 15, 2011. (ADAMS Package Accession No. ML113200081)

5. NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants" (SRP), Section 4.2, "Fuel System Design," Revision 3, dated March 2007. (ADAMS Accession No. ML070740002)

6. GEH TR NEDE-33284P-A, Revision 2, "Marathon-5S Control Rod Assembly," dated October 2009. (ADAMS Package Accession No. ML092950277)

7. GE Nuclear Energy TR NEDE-31758P-A, "GE Marathon Control Rod Assembly," dated October 1991. (ADAMS Legacy Library Accession No. 9107090009)

8. Letter from GEH to NRC, MFN 11-184, "Marathon Control Rod Assembly Surveillance Program Update," dated June 16, 2011. (ADAMS Accession No. ML1116714280)

9. SCALE: A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation, ORNL/TM-2005/39, Version 6, dated January 2009.

Attachment: PNNL Evaluation

Principal Contributors: Paul M. Clifford, NRR
Amrit Patel, NRO
Chris Van Wert, NRO

Date: